Characterizing Adopter and Non-Adopter of Photovoltaic System in Indonesia

Nurwidiana Nurwidiana, Bertha Maya Sopha and Adhika Widyaparaga
Mechanical and Industrial Engineering Department
Universitas Gadjah Mada
Indonesia
Industrial Engineering Department
Sultan Agung Islamic University
Indonesia
nurwidiana@mail.ugm.ac.id, nurwidiana@unissula.ac.id ,bertha_sopha@ugm.ac.id, adhika@ugm.ac.id

Abstract

Transitioning to renewable energy requires a micro approach at the household level as decision-makers. This paper investigates the characteristics of photovoltaic (PV) system adopters and non-adopters of photovoltaic (PV) systems in Indonesian households to recognize household heterogeneity and explores empirical facts regarding the critical factors influencing PV system adoption. A survey of 450 households was conducted in 2020. The results showed that the adopter and non-adopter groups differed significantly in their activeness in seeking information about PV and the recommendations received for using PV. However, the effect of suggestions and sources of information was the same between the two groups. Both groups have the same perception of the benefits derived from PV systems and the high investment costs. However, they are significantly different in perceptions of the complexity of using PV systems. The research shows that the adopter group is an early adopter, while the non-adopter group has late adopter characteristics. Regarding environmental value, the two groups did not show a significant difference concerning the problem of awareness and responsibility for using renewable energy. However, they differed in willingness to pay more for using renewable energy. Electricity bill reduction, energy independence, and environmental friendliness are the three primary motivators for adopting groups to install PV systems. Meanwhile, in the non-adopter group, high installation costs, access to installation services, and lack of information were encountered as the main obstacles to adoption. The non-adopter group will be willing to use the PV system if given a 55% subsidy of the investment cost and when the payback period is not more than 8 years.

Keywords
Adopters, Non-adopters, Photovoltaic systems, Indonesian households, Motivation, Barriers

1. Introduction

Population growth and increased economic activity led to higher electricity demand. Currently, the electrical energy supply depends on fossil fuels such as oil, coal, and gas. The electricity supply faces environmental issues such as increased greenhouse gas emissions, global warming, and the depletion of fossil resources. The transition to renewable energy sources is a must in electricity supply. The Indonesian government is targeting the provision of 45.2 GW of sustainable electricity to support the achievement of the target of 23% renewable energy in the national energy mix by 2025 (MEMR, 2021a). As alternative energy with matured technology and abundant sources in Indonesia, solar power is expected to contribute 6.5GW through photovoltaic (PV) technology (MEMR, 2021a). Given the modular nature of PV technology, the Indonesian government is pushing for rooftop PV applications and is targeting 1.5GW of electricity generated from this program. PV systems make households act as prosumers who consume electricity from the grid and can generate their electricity (Nugraha et al., 2020). In several studies, the presence of prosumers has proven to be a solution for providing sustainable energy (Kumar and Saha, 2015; Sato, 2016).

The Indonesian government regulates PV use through Ministerial Regulation Number 49 of 2018, issued by the Ministry of Energy and Mineral Resources (MEMR). This regulation allows PV adopters to send their excess PV electricity to the State-owned Electricity Company (PLN) grid and calculated to reduce electricity bills for the following month. This effort aims to encourage households to use PV systems as an alternative source of electricity to reduce electricity consumption from fossil fuels. However, the diffusion of the PV system market has been relatively slow so far. Uuntil mid-2021, rooftop PV adopters only reached 4028 with a total capacity of 35 MW (MEMR, 2021b), still far from the target of 3.5 GW in 2025.

According to the Diffusion of Innovation theory, the heterogeneity, communication channels, the type of innovation-decision, and the perceived attributes of the innovation will influence the adoption rate (Roger, 2010). Adopting technology at the household level has a unique role in energy transition (Mittal et al., 2019). Appropriate policy design to encourage PV adoption requires understanding the mechanisms of adoption by households which are often influenced by heterogeneity and the influence of social interactions. Previous studies investigated adopters and non-adopters of PV systems in Indonesia. The result proved that both groups significantly differed in socio-demographic and social influence (Nurwidiana et al., 2021). In line with diffusion theory, the adopter group has a higher income level and receives recommendations from more people to use PV. Policy exploration also requires understanding the processes and attributes that influence households' decision-making (Moglia et al., 2017). The effect of another aspect on PV adoption intentions in Indonesian households is an exciting study.

This paper will explore the adopters and non-adopters of PV systems in Indonesia on various other factors that are key aspects of adoption. There are two things behind this study. First, complement previous studies that have identified the potential use of renewable energy in Indonesia on a macro basis (Maulidia et al., 2019), especially solar energy (Silalahi et al., 2021), which requires a micro approach at the household level as a decision making in PV investment (Sommerfeld et al., 2017). Second is the need to understand household perceptions of the PV system as a basis for empirical evidence for policymakers. The investigation explores the differences between adopters and non-adopters concerning several key adoption points. The study also identified the motivations of adopters to use the PV system, the barriers felt by non-adopters, and the technical and financial policies that this group believes are necessary to be willing to switch to a PV system. The results of this study help recognize empirical facts about the critical factors that influence the adoption of PV systems by Indonesian households. The implication is a basis for designing appropriate policies for each target group to encourage PV system adoption.

2. Literature Review

Knowledge of how individuals make decisions in the energy transition is helpful for policymakers to determine appropriate policies to encourage the adoption of renewable energy. This section describes the theories relevant to energy transition decision-making to get to a critical point in adoption decisions.

2.1 Diffusion of Innovation

Diffusion of Innovation (DoI), introduced by Roger, explains the process of an innovation communicated through specific channels over time to a group of social system members (Roger, 2010). There are four main elements in the diffusion of innovation: innovation, communication channels, period, and social system (Roger, 2010). Adopting innovations in social systems does not occur simultaneously but rather is a process in which some people are more likely to adopt an innovation. There are five categories of adopters: innovators, early adopters, early majority, late majority, and laggards. Innovators are the first group to adopt new technology because they are interested in the novelty of the technology. Early adopters are also a group that adopts technology early because they want to be at the forefront. The early majority group makes decisions based on the utility and practical benefits of the innovation. The late majority is similar to the early majority but is more considered when adopting. The last group is laggards, slow to adapt to new ideas or technologies, and they tend to adopt only when they are forced to or because everyone else is already doing it.

2.2 Theory of Planned Behavior

The decision to adopt a PV system is considered a complex behavior because of the high investment costs, the effort involved, and the uncertainty of the outcome. Theory of Planned Behavior (TPB) was widely used to investigate environmental behavior, such as the transition to renewable energy (Moglia et al., 2017). TPB states that behavior occurs because of an intention determined by attitudes, subjective norms, and perceived behavioral control (Ajzen, 1991).

Attitudes result from a general assessment based on individual perceptions of the utility of innovation. Adoption occurs when an invention provides an expected relative advantage (Ajzen, 1991). In the context of PV system adoption, Korcaj et al. provide five specific benefits (relative advantage) and one cost factor that explains attitudes toward PV. The specific benefits are (1) environmental benefits, (2) economic, (3) autarky, (4) financial, (5) social status, and (6) overall costs (Korcaj et al. al., 2015).

Subjective norms are perceived social pressures and demands for certain behaviors (Ajzen, 1991). Norm formation is based on two things firstly, the perception of what the reference group does, and the second, the demands of the reference group. The importance of reference groups for decision-makers will affect compliance with norms. So, this study also investigates the difference in the influence of references on PV adoption decisions by adopters and non-adopters.

2.3. New Environmental Paradigm

Dunlap and Liere formulated the New Environmental Paradigm (NEP) in 1976 to establish the validity of fundamental values and belief systems for the environment and find confirmation of empirical findings. NEP is intended to measure public attention to environmental quality or respect for the environment (Dunlap and Van Liere, 1978). The NEP is equipped with a study of three environmental behaviors, namely egoistic, altruistic, and biosphere ecological concern, as a measure of belief in the consequences of environmental conditions for individuals.

Jager (2006) found that the altruistic values of the NEP are a significant factor in predicting the rate of PV system adoption. This study explores whether there are differences in the orientation of these values to adopters and non-adopters. This research used ten problem awareness questions from Jager (2006) to measure environmental concerns. Further investigation is carried out by submitting a statement about the willingness to pay more to use renewable energy.

2.4. Consumer Behavior Theory

Based on consumer behavior theory, meta-theory explains consumer behavior in making choices. According to the meta-theory, there are four types of decision strategies: repetitive, deliberation, imitation, and social comparison. (Jager et al., 2000). First imitation strategy, consumers use products that have been used before. Consumers will evaluate all options in the deliberation strategy and choose the product with the highest utility value in the deliberation strategy. The third is imitation. Consumers will choose products with the largest market share. Finally, in social comparison, consumers compare products used previously with other products widely used in their social environment and choose the product with the highest value.

3. Materials and Methods

3.1 Sample

The sample consists of two groups: the adopter and non-adopter. Adopter is households that have used the PV system. Contrarily, non-adopter have not used the PV system. Data was collected through online surveys to reach respondents on a national scale. Questionnaire form links were sent to PV discussion groups on various social media to get responses from adopter groups. The non-adopter group data was collected through snowball sampling by sending a questionnaire link through various social media applications. The unit of analysis of this research is a household. Only homeowners are recognized as respondents because they are considered decision-makers regarding PV system adoption. The questionnaire was sent in early November 2020, after five weeks of getting 450 responses, 46 (10%) from adopters and the rest from non-adopters. Of the 450 answers received, the sorting is done based on homeownership status, decision-making authority, and completeness of answering the questionnaire. After the screening, 413 results were left for analysis, 367 were non-adopters, and 46 were from the adopter group.

3.2 Measure

The questionnaire was organized into four parts, the first part asking about the environmental values. Respondents' environmental problem awareness was measured using question items from Jager (Jager et al., 2000), which adopts the New Environmental Paradigm (NEP) scale based on the work of Dunlap and Van Liere (1978). The second part contains questions to analyze perceptions toward renewable energy (RE) and PV systems for household electricity. Questions are structured based on five precursors of attitude towards PV from Korcaj et al. (2015), namely environmental benefit, financial, social, autarky, and overall costs. Attribute ease of use and ease of installation was added to measure the perceived complexity of the PV system. The third part addressed the respondents' communication habits and sources of information when making decisions about electricity. The last part assesses the household decision-making process. This section wants to know adopter characteristics and decision-making strategies, adopters' motivation, and perceived barriers of non-adopters to using the PV system. Furthermore, non-adopter respondents were asked about the expectation of technical and financial facilitation from the government and the PV industry to be willing to use PV.

A pilot study was conducted to test and refine the questionnaire. Furthermore, the questionnaire was distributed to 30 respondents to test its validity and reliability. The analysis is divided into five parts: 1) Information and social interaction, 2) Problem awareness and attitudes toward renewable energy, 3) Perception toward PV systems, 4) Decision-making strategies, 5) Motivation, barriers, and facilitating expectation. Statistical analysis was carried out to investigate the differences between the two groups. Pearson's Chi-square test for nominal data and analysis of variance (ANOVA) was used for interval data. Meanwhile, a non-parametric test was used with Mann Whitney U for ordinal data.

4. Results and Discussion

4.1 Information and social interaction

Information channels and social systems are one of the main elements in the diffusion process (Roger, 2010). This section examines the delivery of information and interactions in adopting PV systems in Indonesian households. The data are presented in Table 1.

Table 1. Information and communication

Parameters	Adopter ($N = 46$)		Non-adopter ($N = 367$)		Significance test
Interval data	Mean	S.D	Mean	S.D	ANOVA
Number of peers communicated with about energy and or electrical system	21.26	28.57	4.12	7.70	F = 84.521, $p < 0.001$
Number of recomenders	7.11	8.75	1.29	4.50	F = 69.83 , $p < 0.001$
Influence of recommendations on decision making (%)	28.61	26.14	31.83	25.41	F = 0.658 , $p = 0.481$
Ordinal data	Mean	S.D	Mean	S.D	Mann Whitney U
Proactive information search*)	4.24	0.91	2.86	1.37	Z = - 8.808 , $p < 0.001$
Understand PV technology as renewable energy*)	4.11	0.81	2.28	1.10	Z = - 8.883 , $p < 0.001$
Nominal data	*N*	%	*N*	%	Chi² test
Information sources					
1 = Internet	28	60.9	217	59.1	$X^2 = 4.90$
2 = Family / friend	15	32.6	139	37.9	$df = 5$
3 = Social media	15	32.6	125	34.1	$p = 0.428$
4 = Distributor / vendor PV	12	26.1	26	7.1	
5 = Goverment / PLN	0	0.0	11	3.0	
6 = No information yet	0	0.0	7	1.9	

Note : *) Score : 1 (low) - 5 (High)

There are significant differences in the number of peers and the number of recommendations received by each group. The adopter group discussed with more people about energy and got more suggestions for using PV systems than the non-adopter group. However, the influence of other people on decision-making in the two adopter groups was not significantly different. This result shows that other people's opinions have the same weight of influence in decision-making for both groups. However, the adopter group received more recommendations, so they tended to adopt PV.

This research tested the information seeking and information obtained about PV systems between the two groups of respondents, and the results were significantly different. The adopter group is more active in seeking information about PV systems and is more familiar with PV technology. This finding aligns with adoption theory, where adopters seek more information, interact with innovators, and have closer contact with scientific sources (Roger, 2010). Information sources from both adopter groups were asked, and respondents could choose more than one source of information. Statistical tests prove that there is no significant difference between the two. The internet is the most widely used source of information by both groups. The dominance of searching for information through the internet causes the distance to no longer as a limitation for exchanging information about PV systems. In the non-adopter group, several respondents do not know about PV systems, which is an obstacle to increasing PV adoption. PV distributors and PLN still have a limited role as sources of information due to the limited presence of PV vendors, especially outside Java Island.

4.2 Problem Awareness and Attitudes towards Renewable Energy

Environmental concern is measured by ten questions of problem awareness from Jager et al. (2000). Attitudes towards renewable energy (RE) are tested through two parameters: a sense of responsibility in using RE for environmental sustainability and willingness to pay more to use RE. Answers are presented in the form of a Likert scale with a value of 1 (strongly disagree) to 5 (strongly agree). The Mann-Whitney U test was conducted to determine differences in perceptions between the adopter and non-adopter groups. The results are presented in Table 2.

Table 2. Perception of environment and renewable energy

Parameters	Non-adopter		Adopter			
	Mean	S.D	Mean	S.D	*Z*	*p*
Problem awareness	4.28	0.63	4.06	0.88	-1,603	0.109
Responsibility to use RE	4.18	0.75	4.33	0.67	-1.125	0.260
Willingness to pay more to use RE	3.51	1.08	3.96	1.11	-2.988	0.003

The results showed no significant difference between the two groups regarding problem awareness and responsibility for using RE. Interestingly, it was found that there was a significant difference in willingness to pay more for renewable energy ($p < 0.05$). The adopter group had a higher willingness than the non-adopter. Furthermore, a correlation test was conducted with the Spartan Rho to determine the relationship between the responsibility to use RE and the willingness to pay more to use RE in each group of respondents.

Spearman's rho test on the adopter group gave $p < 0.001$ with a correlation coefficient value of 0.515, indicating a relationship between the two variables with a strong relationship level. When someone feels responsible for using RE for environmental sustainability, he will also be willing to pay more. Meanwhile, in the non-adopter group, the *Spearman's rho* test gave $p < 0.001$ with a correlation coefficient of 0.212, which means that the two variables have a very weak relationship. Non-adopters, even though they have a sense of responsibility to use RE, are not necessarily willing to pay more to use RE. This finding is consistent with studies of pro-environmental behavior often find a gap between what people say they value and what they do (Newton and Meyer, 2013).

4.3 Perception toward PV systems

Perceptions of technology attributes need to be understood, considering that innovation attributes are explained by 49% - 87% of the variance in technology adoption (Roger, 2010). In this study, five predictors from Korjac et al.(2015) were used as attributes of the PV system, environmental benefits, financial benefits, social benefits, autarky benefits, and overall costs. In addition, attribute of ease of use and ease of installation is added to measure the perception of the complexity of the PV system. The description of each predictor and the average value of the adopter and non-adopter groups are presented in Table 3.

The results show that the two groups agree on the perception of the benefits obtained and the investment costs of using PV systems for environmental, financial, and social benefits. Likewise, in terms of costs, both groups have a perception that PV investment is expensive. Significant differences are found in the perception of energy independence, ease of use, and ease of installation. The non-adopter group has the perception that PV installation is difficult and complex in its operation and maintenance, and this perception seems to be a barrier to PV adoption. Answers are presented in the form of a Likert scale with a value of 1 (strongly disagree) to 5 (strongly agree)

Table 3. Perception of PV system attributes

Attributes	Description	Adopter		Non Adopter		Mann Whitney U test	
		Mean	S.D	Mean	S.D	*Z*	*p*
Environmental Benefit	Perceptions of benefits in environmental sustainability aspects derived from the use of PV systems	4.23	0.07	4.28	0.03	-0.721	0.471
Social Benefit	Perception of the increase in social views obtained when using the PV system	3.41	0.17	3.21	0.05	-1.414	0.157

Financial Benefit	Perception of the savings obtained when using a PV system	2.79	0.13	3.80	0.04	-0.018	0.985
Autarky Benefit	Perception of perceived energy independence when using solar PV	4.04	0.12	3.71	0.04	-2.935	0.003
Overall Cost	The perception is that installing and maintaining a PV system is expensive.	3.58	0.15	3.49	0.05	-0.764	0.445
Ease of Use	The perception is that PV systems are easy to use and maintain.	3.63	0.16	3.18	0.04	-3.563	< 0.001
Ease of installation	Perceptions of the ease of switching to electrical systems with PV	2.85	0.25	1.39	0.06	-6.837	< 0.001

4.4 Decision-Making Strategies

This section discusses decision-making strategies based on meta-theory from Jager (2006) and adopter classification in technology acceptance based on Roger classification. Both data are presented in Table 4. The analysis is divided into two parts and is described below.

Table 4. Characteristics of decision making

Variables	Adopter (N = 46)		Non Adopter (N= 367)		Significance test
Nominal Data	n	%	N	%	Chi^2 *test*
Decision Strategy					
1. Repetition	5	10.9	18	4.9	
2. Imitation	5	10.9	8	2.2	X^2 = 17.556
3. Deliberation	32	69.6	246	670	*df* = 3
4. Social Comparison	4	8.7	95	25.9	*p* < 0,001
Adopters Categories					
1. Innovator	19	4.3	46	12.5	X^2 = 31.544
2. Early adopter	10	21.7	53	14.4	*df* = 4
3. Early majority	7	15.2	84	22.9	*p* < 0.001
4. Late majority	8	17.4	139	37.9	
5. Laggards	2	4.3	45	12.3	

The first part is statistical tests on decision-making strategies based on meta-theory. The results showed a significant difference between the two groups. The non-adopter group majority uses a social comparison strategy that shows their dissatisfaction with the electricity system. Meanwhile, the adopter group used a lot of repetition and imitation strategies. The adopter group in areas with electricity grids choosing a repetition strategy showed the intention to continue using the PV system. In contrast, adopters in areas without a PLN electricity network imitate their surrounding neighbors who have used a PV system.

Second, analyzing the characteristics of the sample based on Roger's adopter classification, which states that 2.5% are innovators, 13.5% are early adopters, 34% are an early majority, 34% are a late majority, and 16% are laggards. Statistical tests between non-adopter samples and Roger's theory prove that at the 0.1% significance level, there is no significant difference between the two (X^2 = 12.89, df = 4, p = 0.0012). These results show the characteristics of Indonesian households following Roger's theory. Meanwhile, the test between the adopter and non-adopter groups showed a significant difference. The majority of the adopter group are innovators who will use the PV system even when no one in their environment uses the technology. Meanwhile, the non-adopter group majority are late followers of innovation who will be willing to use technology if most of their colleagues in their environment are already using it.

4.5 Motivators, Barriers, and facilitating exected to PV System Adoption

This section investigates the underlying motivations of adopting groups for installing PV systems. On the non-adopter side, identified perceived barriers and facilitation are needed to be willing to adopt PV systems (Figure 1).

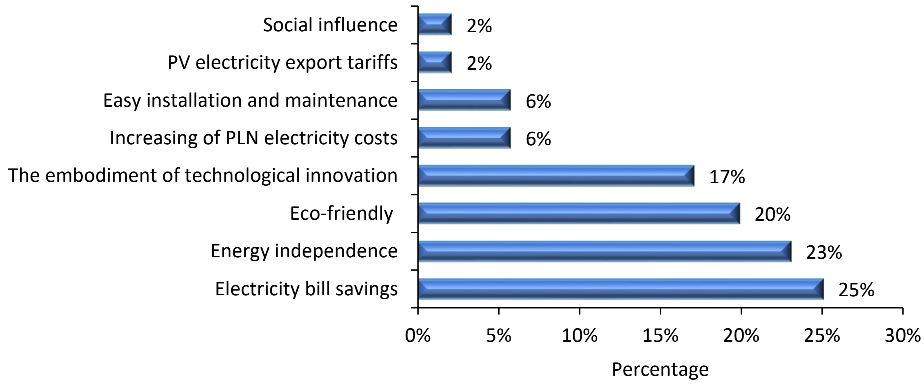

Figure 1. Adopter motivation to use PV system

In line with the findings of Karakaya et al. (2015), the three primary motivators of adopters are electricity bills savings, energy independence, and environmental reasons. Savings obtained from PV systems are the biggest motivation for adopters. The following motivation is energy independence, not depending on electricity from PLN, still having electricity intake when a power outage from PLN underlies this. While the reason for being environmentally friendly only ranks third. However, the government's policies regarding PV are not enough to be a motivation to use solar PV. This result is in line with the results of a survey of 745 PLN customers, of which 65% said they were interested in using PV but were still waiting for the new policy (Setyawati, 2020).

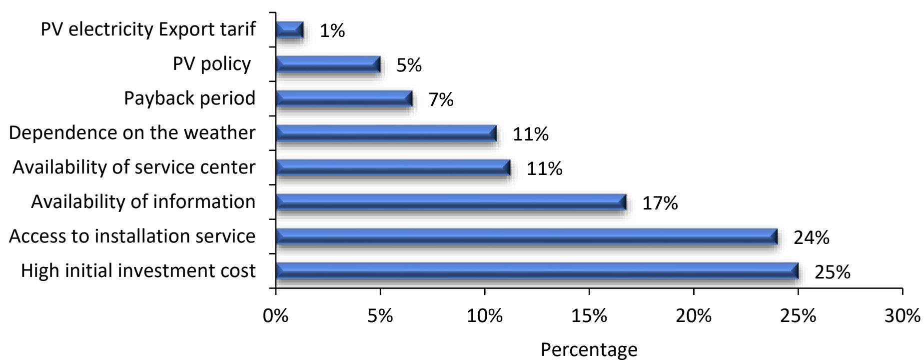

Figure 2. Non-adopter barriers to using the system

Figure 2. shows what factors hinder the adoption of PV by non-adopter groups. The initial cost was the main barrier felt by non-adopters, in line with the findings of previous researchers (Karakaya and Sriwannawit, 2015; Schelly, 2014). The next obstacle is access to installation service providers, related to the presence of a distribution center centred on the island of Java. Even though the company serves PV installation outside Java, the distance causes a low trust value. These results corroborate Palm's assertion that finding a trusted, professional, and competent installation company is currently a demand for PV adoption (Palm, 2018). Availability of information becomes the next obstacle.

Next, we examine factors relating to the financial and technical support that adopters expect to be willing to use PV systems. Respondents were asked to provide statements regarding the importance of these factors in supporting the use of PV systems. Answers are given in the form of a Likert scale with a value of 1 (very unimportant) to 5 (very important t). Table 5. presents the expected support for the two aspects in order of importance.

Table 5. Level of important technical and financial facilitation

No.	Technical facilitating		Financial facilitating	
	Factor	Mean	Factor	Mean
1	Service center in an affordable location	4.53	PV system device grant for remote area	4.35
2	Vendor or distribution center (DC) location is affordable	4.44	Subsidies for purchasing PV system	4.22
3	PV system maintenance training program	4.44	Electricity export rates to PLN	4.12
4	Provision of PV from within the country	4.43	PLN electricity tariff discount	4.02
5	Community empowerment for system maintenance	4.35	Facilitation of PV purchase cost loans	3.85

The affordability location of the service center (SC) and distribution center (DC) as vendor facilities is the most crucial requirement of technical facilitation related to the facility's role as a provider of PV information, installation, and maintenance services. The presence of vendors will increase trust and reduce complexity in using PV systems. Furthermore, the expected SC and DC locations of the adopter and non-adopters groups were analyzed. Pearson chi-square test results show significant differences in the expected SC and DC locations between the adopter and non-adopter groups. More than 90% of non-adopters want the SC and DC locations to be in the same province as the location of their residence. Meanwhile, 40% of adopters are willing to use PV even though the SC dan DC location is in a different province. Even 30% of adopters can accept the Sc and DC location while still in the country (table 6).

Table 6. Technical and financial facility expectations

Variables	Adopter (N = 46)		Non Adopter (N = 367)		Significance test
Technical Facilitation	N	%	N	%	Chi^2 test
The expectation of the location of distribution and or service center (in terms of the respondent's residence)					
In similar province	27	58.7	337	91.8	$X^2 = 42.469$
In the same region	5	10.9	12	3.3	$df = 2$
In the country	14	30.4	18	4.9	$p < 0.001$
Financial Facilitation	Mean	stdev	Mean	Stdev	Anova
Expected subsidy (%)	39.21	24.37	54.74	23.46	$F = 16.067$ $p < 0.001$
Expected Payback Period (years)	8.04	2.19	8.33	2.723	$F = 3.489$ $p = 0.488$
PV export rates on net metering (%)	77	19	64	16	$F = 26$ $p < 0.001$

PV system equipment grant for the remote area is essential financial facilitation. Meanwhile, for sites connected to the PLN network, the need for subsidies and determining export tariffs are demands from respondents. The two groups show significant differences in expectations of subsidies for purchasing PV systems and export tariffs electricity from PV systems to PLN. The non-adopter group set a subsidy value of 54.74% higher than the adopter group, which gave 39.21%. Interesting findings on expected electricity export tariffs from solar PV to PLN, the non-adopter group showed an average export tariff value of 64% lower than the current export tariff (65%). This condition is triggered by a lack of understanding of the current regulations, indicating a lack of socialization of regulations regarding PV systems.

Meanwhile, the adopter group demands a higher export tariff of 77% because, based on their experience, the current export value of 65% is not profitable enough. In the expected value of the payback period, there is no significant difference in returns of the two groups giving a value in the range of 8 years.

5. Conclusion

This study provides an exciting insight into the adoption of PV systems in Indonesian households by investigating the differences between PV system adopters and non-adopters for several factors generally recognized as key points in adoption studies. The statistical test showed significant differences between the two groups regarding the number of recommendations received, activeness in seeking information, willingness to pay more for using PV, the perceived complexity of using PV, decision strategies, and adopter characteristics.

Referring to Rogers' adopter classification, the adopter group is dominated by early adopters; on the other hand, the non-adopter group follows the late majority criteria. Both groups have the same awareness of environmental problems and the responsibility to use RE. However, both groups differed significantly in their willingness to pay more to use RE, whereas the adopter group had a higher willingness. Regarding the perception of PV systems attributes, both groups have the same perception that PV systems provide environmental, financial, and social benefits. Both groups also agree that PV systems are expensive. However, the non-adopter group has more perceptions regarding the complexity of using PV systems. This finding indicates that the perception of the non-adopter group that the PV system is challenging to install and use is one of the obstacles to adoption. Here, the role of the PV industry is needed to provide explanations for non-adopters to reduce the perception of complexity.

The results show that the desire to reduce electricity bills, energy independence, and environmental friendliness are the three primary motivators for the adopter group to install a PV system. Meanwhile, non-adopter perceived barriers to adopting PV systems are the high investment cost, demanding access to PV system installation service providers, and lack of information. In addition, this research found that the financial facilitation expected by non-adopters to adopt PV, namely the existence of a minimum subsidy of 55% and an investment payback period of not more than eight years. Interesting findings on the expected value of PV electricity export tariffs to the PLN network. Non-adopters expect export tariffs of 64%, slightly below the current value of 65%. Although the current export tariffs have met the non-adopters expectations, they have not yet adopted the PV system. There may be two reasons: investment costs that are still too high as an obstacle to adoption, without any financial support (including subsidies or grants). And the second reason is the lack of information so that the non-adopter groups do not understand the current export tariffs and the calculation mechanism. For this reason, more intensive socialization is needed.

The adoption of PV systems faces financial and technical challenges and the availability of information. This study helps policymakers understand the drivers of adoption decisions and the barriers that hinder non-adoption. The expected financial and technical facilitation by non-adopters will enable policymakers to design appropriate policies to support the development of the PV systems market.

References

Ajzen, I., The theory of planned behavior. *Organizational behavior and human decision processes*, Vol.50, No.1, pp.179–211, 1991.

Dunlap, R. E., and Van Liere, K. D., The "New Environmental Paradigm" a proposed measuring instrument and preliminary results. *Journal of Environmental Education*, Vol.9, No.4, pp.10–19, 1978.

Jager, W., Stimulating the diffusion of photovoltaic systems: A behavioural perspective. *Energy Policy*, Vol.34, No.14, pp.1935–1943,2006.

Jager, W., Janssen, M. A., De Vries, H. J. M., De Greef, J., and Vlek, C. A. J., Homo psychologicus in an ecological-economic model. *Ecological Economics*, Vol.35, pp.357–379, 2000. Retrieved from https://www.rug.nl/staff/w.jager/janssen_jager_devries_degreef_vlek_ee_2000.pdf

Karakaya, E., and Sriwannawit, P., Barriers to the adoption of photovoltaic systems: The state of the art. *Renewable and Sustainable Energy Reviews*, Vol.49, pp.60–66, 2015.

Korcaj, L., Hahnel, U. J. J., and Spada, H.,Intentions to adopt photovoltaic systems depend on homeowners' expected personal gains and behavior of peers. *Renewable Energy*, Vol.75, pp.407–415, 2015.

Kumar, B. M., and Saha, B. B.,Energy security and sustainability in Japan. *Evergreen*, Vol.2, No.1, pp.49–56, 2015.

Maulidia, M., Dargusch, P., Ashworth, P., and Ardiansyah, F., Rethinking renewable energy targets and electricity sector reform in Indonesia: A private sector perspective. *Renewable and Sustainable Energy Reviews*, Vol.101, No.October 2018, pp.231–247, 2019.

MEMR, Rencana Usaha Penyediaan Tenaga Listrik (RUPTL) PT PLN (Persero) 2021-2030. *Rencana Usaha Penyediaan Tenaga Listrik 2021-2030*, 2021a.

MEMR, *Laporan Kinerja DITJEN EBTK Tahun 2021,2021b*.

Mittal, A., Krejci, C. C., and Dorneich, M. C.,An agent-based approach to designing residential renewable energy systems. *Renewable and Sustainable Energy Reviews*, Vol.112, No.May, pp.1008–1020, 2019.

Moglia, M., Cook, S., and McGregor, J., A review of Agent-Based Modelling of technology diffusion with special reference to residential energy efficiency. *Sustainable Cities and Society*, Vol.31, pp.173–182, 2017.

Newton, P., and Meyer, D.,Exploring the attitudes-action gap in household resource consumption: Does "Environmental Lifestyle" segmentation align with consumer behaviour? *Sustainability (Switzerland)*, Vol.5, No.3, pp.1211–1233, 2013.

Nugraha, G. D., Sudiarto, B., and Ramli, K., Machine learning-based energy management system for prosumer. *Evergreen*, Vol.7, No.2, pp.309–313, 2020.

Nurwidiana, N., Sopha, B. M., and Widyaparaga, A., Behavioral Factors Underlying Households ' Intention Toward Solar Photovoltaic Adoption. *Proceedings of the 2nd Asia Pacific International Conference on Industrial Engineering and Operations Management,* pp. 737 - 749, Surakarta, Indonesia, September 14 - 16, 2021.

Palm, J., 2018, Household installation of solar panels – Motives and barriers in a 10-year perspective. *Energy Policy*, Vol.113, No.February 2018, pp.1–8.

Roger, E. M., *Diffusion of Innovation* (Fourth.). New York: Free Press, 2010

Sato, T., How is a sustainable society established? A case study of cities in Japan and Germany. *Evergreen*, Vol.3, No.2, pp.25–35, 2016.

Schelly, C., Residential solar electricity adoption: What motivates, and what matters? A case study of early adopters. *Energy Research and Social Science*, Vol.2, pp.183–191, 2014.

Setyawati, D., Analysis of perceptions towards the rooftop photovoltaic solar system policy in Indonesia. *Energy Policy*, Vol.144, No.August 2019, pp.111569, 2020.

Silalahi, D., Blakers, A., Stocks, M., Lu, B., Cheng, C., and Hayes, L., 2021, Solar PV Resource Assesment for Indonesia's Energy Future. *Conference Record of the IEEE Photovoltaic Specialists Conference*, pp.178–181.

Sommerfeld, J., Buys, L., and Vine, D., Residential consumers' experiences in the adoption and use of solar PV. *Energy Policy*, Vol.105, No.December 2016, pp.10–16, 2017.

Acknowledgments
The authors are grateful to the Ministry of Education and Culture (KEMENDIKBUD) for funding support for this research through the Doctoral Dissertation Research (PDD) grant program grant scheme (2022).

Biography
Nurwidiana is an Assistant Professor of Industrial Engineering Program, Faculty of Industrial Technology, Universitas Islam Sultan Agung (UNISSULA), Indonesia. She earned her bachelor's degree in industrial engineering from Muhammadiyah University of Magelang, Indonesia, and a master's degree in industrial engineering from the Institut Teknologi Sepuluh November, Indonesia. She is a Ph.D. candidate at the Universitas Gadjah Mada, and now she is pursuing a Ph.D. with a research focus on photovoltaic energy systems. She has recently published some of her research results in the Evergreen Journal.

Bertha Maya Sopha is an Associate Professor of Industrial Engineering Program, Department of Mechanical and Industrial Engineering, Universitas Gadjah Mada, Indonesia. She currently serves as a chair of the Indonesian Association of Industrial Engineering Higher Education Institution (BKSTI) and vice-president of IEOM Indonesia Chapter. She earned a Bachelor of Engineering (best graduate) from Universitas Gadjah Mada, a master's degree of Management of Production specialization in Transportation and Logistics (graduate with distinction) from the Department of Industrial Economics and Technology Management, Chalmers University of Technology, Sweden. She holds a Ph.D. from the Industrial Ecology Programme, Norwegian University of Science and Technology (NTNU), Norway. She has maintained a high quality of research throughout her academic career, including international scholarly leadership in the areas of supply chain management and logistics, industrial ecology, and complex system modeling. She has received various academic achievements, awards, and recognitions such as Distinguished Woman in Industry and Academia (WIIA) by IEOM Society, the Best Lecturer runner-up at Universitas Gadjah Mada, best paper awards at several international and national conferences, and research grantee awards from both Indonesia and abroad institutions. She has also been active as a journal reviewer in both reputable international journals and national journals.

Adhika Widyaparaga is an Assistant Professor of Mechanical Engineering Program, Department of Mechanical and Industrial Engineering, Universitas Gadjah Mada, Indonesia. He currently serves as vice-head of the Mechanical and Industrial Engineering Department. He earned a Bachelor of Engineering from Universitas Gadjah Mada, and a master's degree in Biomedical Engineering from The University of New South Wales, Australia. He holds Doktor from Mechanical Engineering, Kyushu University, Japan. He is a researcher in the Center of Energy Studies Universitas Gadjah Mada with the area of interest including Biofluid dynamics, Microfluidics, Thermoacoustic temperature control, and energy generation. In addition to actively publishing his work in international journals and conferences, He is also a peer reviewer for The International Journal "Cryogenics (Elsevier)" and the International

Journal "Applied Thermal Engineering (Elsevier)." He also carried out a number of energy project activities, including with Indonesia Power, Toyota Motor Company, Toyota Motor Manufacturing Indonesia, and Pertamina.